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ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

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http://193.49.43.2:8080/smis/servlet/UserUtils?start

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Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF	**Experiment title:** Grazing-incidence diffraction in laterally self-patterned III-V ternary alloys	**Experiment number**: SI-675
Beamline: ID10B	**Date of experiment**: from: April 18, 2001 to: April 23, 2001	**Date of report**: August 27, 2001
Shifts: 15	**Local contact(s)**: Dr. Bernd Struth	*Received at ESRF:*

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Report:

Spontaneous lateral composition modulation (LCM) in III-V semiconductors modifies significantly their optoelectronic properties. Recent studies show that LCM can be manipulated by growing short-period superlattices of two mismatched components by molecular beam epitaxy (MBE) [1]. Such a superlattice exhibits a lateral modulation of the thicknesses of the layers resulting in a lateral modulation of the mean chemical composition of the superlattice. In evidence of this modulation, lateral satellites around Bragg diffractions in x-ray reciprocal space indicate the formation of LCM on a macroscopic scale [2]. From the distance of these maxima the period of LCM can easily be determined. However, a quantitative determination of the modulation *amplitude* was a subject of a single short paper [2], where the analysis has been based only on a single trial measurement.

The goal of the reported measurement was to determine precisely the modulation of the chemical composition of InAs/AlAs superlattices grown on substrates with different miscuts under various growth conditions. For this purpose, using a wavelength of $\lambda = 1.545$ Å we have performed the following scattering measurements at beamline ID10B:

(1) coplanar asymmetric x-ray diffraction 404 (XRD)
(2) grazing incidence diffraction 400 (GID)
(3) grazing incidence small-angle scattering (GISAXS).

Since we have restricted ourselves only to the zero-order satellite peak of the vertical superlattice, instead of the actual sample structure the x-ray "see" only a vertically averaged single $In_xAl_{1-x}As$ layer, whose chemical composition x is modulated laterally. Here we show only the experimental data of sample EA0532, the results of other samples are similar. The sample consisted of 100 periods, each period contains nominally 1.952 monolayer (mL) InAs and 1.466 mL AlAs. The superlattice stack has been grown by MBE on an InAlAs lattice matched buffer layer deposited on (001) GaAs substrate with miscut 2^o, the direction of LCM was close to [100] and it coincided with the miscut direction.

Fig. 1 shows the XRD reciprocal space map. Apart from the vertical coherent truncation rod at Q_x = 4.15 Å, lateral intensity satellites are visible, from their distance a LCM period of (280±5) Å was determined. The vertical positions of the satellites with negative and positive orders are different (see the green lines in Fig.1). The reason for this shift is not clear yet.

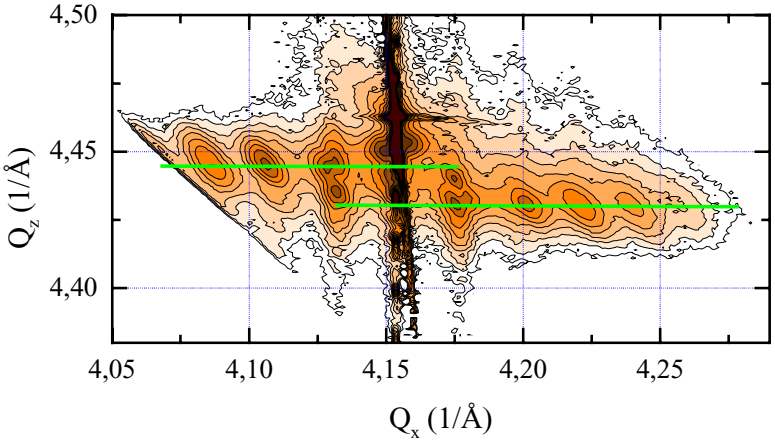
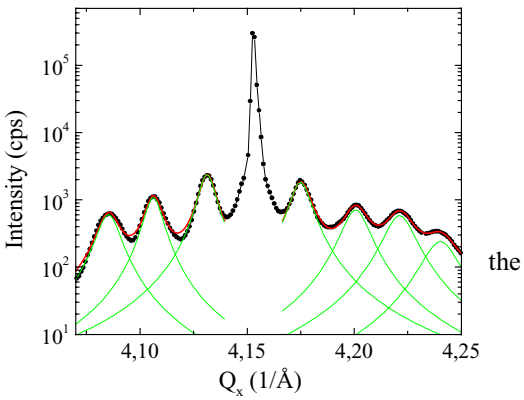


Figure 1. XRD reciprocal space map of sample EA0532, for the meaning of the green lines see the text.

In order to determine the modulation amplitude, we have extracted a linear scan from the measured intensity map and we have fitted the satellite maxima on this scan with lorentzian curves. The areas under these curves (i.e. the integrated intensities of the lateral satellites) were compared with numerical simulations based on anisotropic elasticity theory and kinematical x-ray scattering. The results are shown in Fig. 2.



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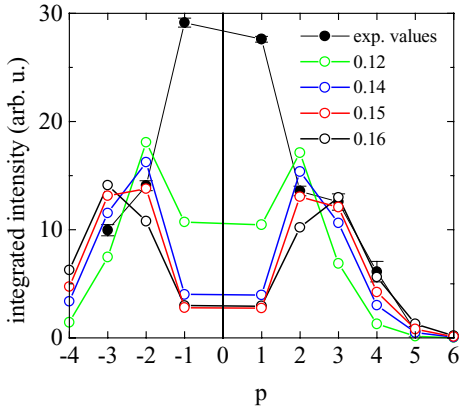
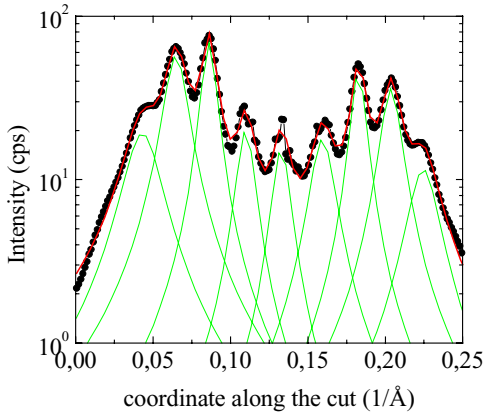


Figure 2. The linear scan extracted from the reciprocal space map (left panel, points) and its fit by a series of Lorentzian curves (red); in the right panel, the integrated intensities of the satellites are compared with theoretical calculations for various amplitudes of the LCM.

The best correspondence with the theory was achieved for the modulation amplitude A = (15±1)%.

Similar results have been obtained in GID. The direction of LCM was slightly inclined from [100] and consequently the lateral satellites were aligned not exactly parallel to the diffraction vector. Therefore, in order to determine the satellite intensities correctly, we have measured a three-dimensional intensity map around the 400 reciprocal lattice point. From this map we have extracted a linear scan along the LCM and again, the integral intensities of the satellites were compared to the theory (Fig. 3.)



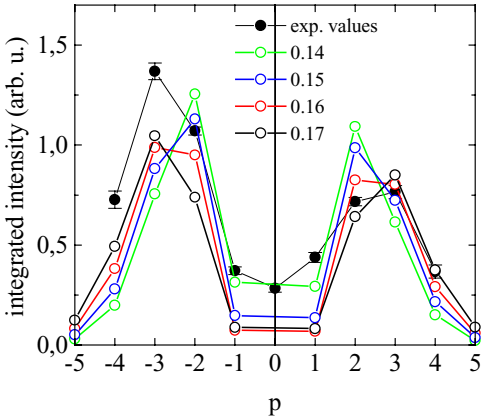


Figure 3. The same situation as in figure 2, grazing incidence diffraction.

From the GID data, the modulation amplitude A = (16±1)% follows.

The XRD and GID methods are sensitive mainly to the lateral *strain* modulation in the sample. In order to study the modulation of the *shape* of the interfaces (i.e. the thickness modulation) we have used GISAXS, which is sensitive only to the density modulation. In the GISAXS geometry, we have measured the

distribution of the scattered intensity in the reciprocal plane Q_z = const, i.e. parallel to the sample surface. The results are plotted in Fig. 4.

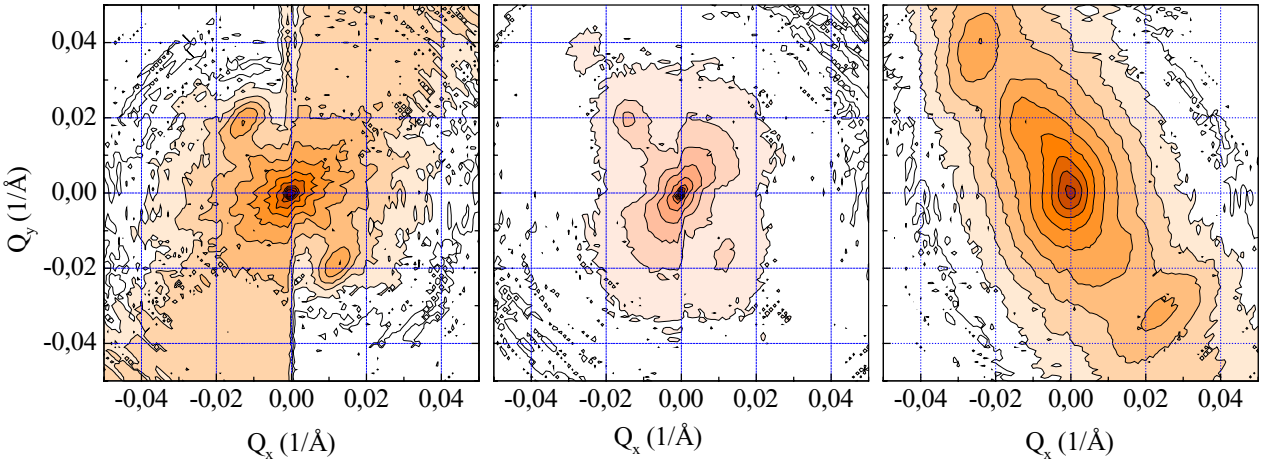


Figure 4. The reciprocal space intensity distributions measured in Q_xQ_y plane parallel to the sample surface in GISAXS for three various values of Q_z 0.028 Å^{-1} (left), 0.335 Å^{-1} (middle) and 0.649 Å^{-1} (right panel).

The maximum in the center of the intensity map is the coherent truncation rod, the lateral satellites due to the LCM are visible up to the ±2nd order. In the analysis of the measured data we have assumed that all the interfaces in the multilayer are similar and the local displacement of the interface from its mean position can be described by the function

$$U(x) = U_1 \cos(2\pi x / L) + U_2 \sin(4\pi x / L),$$

where L is the LCM period and the coefficients $U_{1,2}$ have been determined from the experimental data.

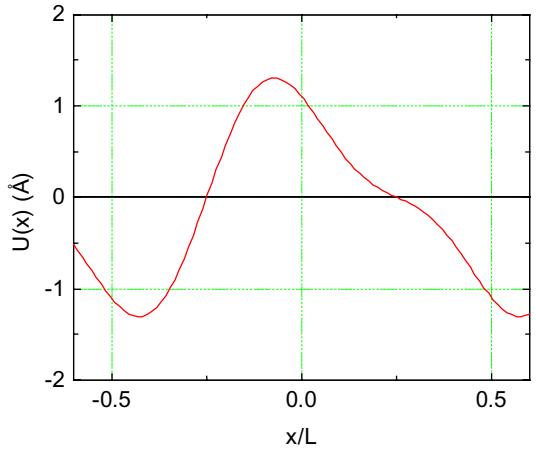


Figure 5. The shape of the interface determined from the GISAXS measurement

In Fig. 5 we have plotted the shape of a single LCM period following from the fit of the GISAXS data to the theory. The shallow wave on the inclined side of the interface shape is a numerical artifact; however, the asymmetry of the interface profile is obvious. This asymmetry does not follow from a macroscopic theory of lateral modulation [3] and most likely, it is caused by a microscopic structure of a vicinal growing surface.

In summary, using x-ray diffraction and small-angle x-ray scattering, we have determined the period, the modulation amplitude and the shape of the lateral spontaneous modulation in a short period InAs/AlAs superlattice. Further studies are necessary in order to improve the resolution in the shape of the modulation.

[1] K. Y. Cheng, K. C. Hsieh, and J. N. Bailargeon, Appl. Phys. Lett. **60**, 2892 (1992).
[2] J. H. Li, V. Holy, Z. Zhong, J. Kulik, S. C. Moss, A. G. Norman, A. Mascarenhas, J. L. Reno, and D. M. Follstaedt, Appl. Phys. Lett. **78**, 219 (2001).
[3] L E. Shilkrot, D. J. Srolowitz, and J. Tersoff, Phys. Rev. B **62**, 8397 (2000).